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MINIMUM REQUIREMENTS FOR ROENTGENOGRAPHY*

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DISCUSSION by John M. Rehfsch, M. D., San Francisco;
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THE physician who has just installed a roentgen equipment or the roentgen diagnostician who is suddenly faced with the problem of roentgenotherapy for the first time is usually appalled at the mass of data given in textbooks on therapy and with which he assumes he must be familiar in order to apply a proper dose of the roentgen ray.

On the other hand, he may believe that all necessary requirements are met if he makes a rough test to ascertain if the "tension" is equal to a "six-inch gap" and then, using the arithmetical formula, confidently gives an epilating dose for tinea tonsurans. On the law of chance and probability one of three things may happen. The hair may fall out, regrow luxuriantly, and the child be cured of its tinea. The hair may not fall out and the child retain the tinea. Or the hair may fall out with resultant cure but without regrowth, the head remaining as bald as the proverbial egg. With the dose estimated and controlled as above, the chances of each of these results occurring are about equal.

There is nothing presented in this paper that is not already known to the experienced radiologist, but it is hoped that the information given will be of use to the inexperienced and a deterrent to those who believe that an exposure of so many minutes constitutes a dose. Nothing will be said of the different methods of estimating dosage. These can be found by those interested in various texts. The recommendations must, in a short paper, be given didactically and are believed by the author to be the minimum requirements. As one becomes experienced one will necessarily use variants according to the nature of the case under treatment and will want to use accurate measuring devices and become familiar with their application. These are not necessary for routine clinical work if one is willing to follow the recommended doses of those working with such instruments. I believe the following recommendations and data are the minimum, and

one unfamiliar with them gives roentgen treatments at the peril of his patients and himself.

BASIC FACTORS

The Quality of the Radiation.—The quality of the radiation is a function of (depends on) the voltage and the voltage must be measured as such, not in inches gap. This was first demonstrated by me in 1921¹ and again by Markley in 1926.² It is most conveniently measured by a sphere gap in routine practice. The quality is also determined by the presence or absence of a filter, its thickness, and the material of which it is made.

The Quantity of the Radiation.—The quantity of radiation is a function of (depends on) the voltage. Because the quantity varied with the square of the voltage when direct current was used in experimental work the error that such a law held true with rectified (rotating switch) current, has been printed in textbooks and more or less assumed in calculating dosage. This is not true. I have reported a series of tests³ showing that, with the one apparatus tested, an error as high as 17.5 per cent in the calculated dose may occur. This error may vary higher or lower with different machines. It is recommended, therefore, that a single voltage be adopted for certain purposes and all tests and doses be based upon it.

Quantity is a function of the milliamperage. Two millimeters in series should always be used in treatment work. Meters not infrequently develop errors and when two are used a difference in reading between the two immediately calls attention to the fact that one of the meters is in error and must be repaired.

Quantity varies inversely with the square of the distance from the focal spot on the target of the tube to the irradiated surface. If the spot is twice as far away the dose will only be one-fourth if all the other factors are the same.

Quantity varies with the port or size of the irradiated area, due to backscattering of rays from the tissue beneath. The following table was made with a standardized instrument at 90 K. V. P. without filter to determine this variation. As it was found that with an area of 2.5 centimeters (one inch) square or less, backscattering could be ignored, the dose for this area was taken as 100. As the dose increases with the size of the port, the number of each port indicates to what per cent the dose or time for 2.5 centimeters² must be reduced to produce equivalent skin effects for each larger port.

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TABLE 1.—At Ninety K. V. P.

Port in square centimeter	Time for equivalent dose
4.5	100
16.0	91
28.0	89
64.0	86
202.0	83

In these measurements 90 K. V. P. was used for the reason that I have used it as a standard in superficial therapy for the last nine years. This voltage when tested against blunt points at sea level will give a sparkover from $5\frac{3}{4}$ to $6\frac{1}{8}$ inches, depending upon atmospheric conditions, and when substituted for the six-inch gap in the arithmetical formula advised by MacKee in the first edition of his book "X-Rays and Radium in the Treatment of Diseases of the Skin," worked out as exactly as could be determined by Sabouraud and Noire pastiles and the epilation of scalp hair.

Quantity is a function of the time. This is obvious. If the exposure is twice as long, twice the dose will be given if all the other factors are the same. Quantity is often spoken of as milliamperes minutes (the number of milliamperes or rate of radiation output times the minutes during which the dose is applied). Five milliamperes for three minutes (fifteen milliamperes minutes) equals three milliamperes for five minutes (fifteen milliamperes minutes). It must not be assumed, however, that this holds true for large variations. The effect of one milliamperes for 100 minutes is not the same as 100 milliamperes for one minute. When the ratio is greater than six to one the effect is greater for the higher milliamperage. In all routine practice, however, milliamperes minutes may be used to express the quantity so far as output and time is concerned.

Determination of Skin Unit for Unfiltered Radiation.—The physician, knowing the above, and with his machine installed, must now determine his skin unit for unfiltered or superficial therapy. It is recommended that the machine be calibrated by the physician for 90 K. V. P., with a sphere gap (the best method, as it is necessary to recheck at intervals) or by the agency installing it. He should then decide at what milliamperage he will operate. The author uses 5 for all his work (except at 200 K. V. P., where the output is 30), as it is convenient to calculate from and cuts the operating time to a minimum. The tube must then be calibrated against human skin. The following method is from MacKee. The factors and time is that recommended by the writer. Assume definite constants, kilovoltage, distance, and milliamperage. Shield an area 2.5 centimeters (one inch) square on the flexor surface of the forearm or the inner aspect of the thigh with lead foil or lead rubber. A young adult or an adolescent with fairly white skin is preferable. For medico-legal reasons the operator should use his own forearm. If the K. V. P. is 90, the milliamperage 5, and the focal skin distance 30 centimeters, expose for three minutes and wait two

weeks for a possible erythema. If none appears increase the exposure 20 per cent. If a definite erythema occurs it is wise to repeat with 20 per cent less. When the dose is determined that will produce a faint but definite erythema, it may be taken as the arbitrary or skin unit. Three-fourths to one of these units is the amount required to produce epilation on the average scalp in tinea tonsurans. One-fourth of this dose given once a week is a common treatment for acne. Five to ten times this dose at one time or fractionated over three to six days is the dose for surface epitheliomata. Obviously it is preferable, for the sake of safety, to standardize on fairly sensitive normal skin. Children are too sensitive for this purpose and this sensitiveness must be borne in mind when treating a child, and the usual dose reduced. Unfortunately the exact amount of reduction is unknown, but it should not be less than 25 per cent in young children. For areas larger than one inch square the dose must be reduced according to Table 1. For instance, if the unit on one square inch was obtained at three minutes and fifteen seconds one-fourth unit given over the entire side of the face would be only 83 per cent of this one-fourth, or approximately forty seconds. As the glass of x-ray tubes vary in thickness the standardization on skin must be repeated whenever the tube is changed.

Determination of Skin Unit for Filtered Radiation.—The determination of the unit skin dose with filtered radiation is not as simple. The skin will tolerate an overdose of filtered radiation that would result in irreparable damage if unfiltered. At the same time injuries from filtered radiation extend deeper beneath the skin and are slower in appearing. In order to obtain a working basis a series of measurements were made at different voltages, filters, and ports.

TABLE 2.—F. S. D. Thirty Centimeters

K. V. P.	millimeters of aluminium	in square centimeters	r per minute at 5 milliamperes
100	1	202	63
100	1	64	57
120	1	202	92
120	1	64	84
120	3	202	50
120	3	64	46
120	4	202	40
120	4	64	37
125	3	202	54
125	3	64	48
125	4	202	45
125	4	64	40

If 400 r (with backscattering) is taken as the minimum erythema dose for low voltage and light filtration, it is seen from the table that with 125 K. V. P., 5 milliamperes, 30 centimeters F. S. D., 4 millimeters of aluminium as filter, and a 64 square centimeter port, such a dose would be given in ten minutes. This would produce a light erythema in some individuals but not in others, and in most cases can be increased 25 per cent (500 r) or more with safety. A dose of more than 500 r of such wavelengths should not be given by an inexperienced physician, although usually safe for the experienced radiologist. It

is always dangerous to give more than 400 r to an area larger than 150 square centimeters and rarely necessary. For practical purposes, with a new installation of the mechanical rectifier type, this table may be assumed to be reasonably correct until the operator can test the skin reactions against the dose. When this is done for any setting, the value obtained may be substituted for that in the table at the voltage and filter used for the clinical observation and a table calculated for the equipment, using the new value as the base and the table for the per cent variation at the other ports, voltages, and filters. It is believed that this method is accurate enough within its range for clinical purposes. The proper dose for other distances is easily obtained from the table and the inverse square law.

For high voltage, heavily filtered radiation, the factors involved are the same except that a larger dose in r's is required to produce a skin reaction and the depth dose becomes of prime importance. With this, as with superficial therapy, it is not necessary to test the quantity of radiation with the ionization chamber. It is absolutely necessary, however, to have a sphere gap as part of the installation. Fortunately Packard⁴ has found that the dose of roentgen rays necessary to kill the eggs of the fruitfly (*Drosophila*) is that required to produce a light erythema on a large proportion of individuals, and full directions for standardizing dosage by this method have been given by Wood.⁵ The number of r's represented by this dose is about 800, including backscattering, and about 500 measured in air. I have, for convenience, called such an amount a 100 per cent dose and found that with my machine it will be obtained at 200 K. V. P., 50 centimeters F. S. D., 0.5 millimeters of Cu and 1 millimeter aluminium filter and a 24 by 24 centimeter port with 300 milliamperes minutes. A reaction severe enough to produce blistering is not usual under 130 to 140 per cent of this amount. In dividing the dose, I found it safe to assume that there is a loss in effect of 7 per cent per day, but it must be understood that the accumulation is not allowed to go above this 100 per cent.

As with superficial therapy, the dose recommended as a standard may be exceeded safely in many instances by an experienced radiologist, and is given solely as a safe starting point for the beginner.

Determination of Depth Dosage.—The technique of cross-firing and determining the depth dose can be obtained from standard textbooks and cannot be discussed here, and the necessity of taking the order in which ports are used in cross-firing into consideration when formulating a course of treatments has been shown in a recent article.⁶

Charting Courses of Treatment for Deep Therapy.—The laying out of a course of treatment and calculation of dosage for so-called deep therapy is much more complicated than for the superficial. A physician, before entering the practice

of short-wave therapy, must study the latest texts and become familiar with all the factors involved. He should also visit radiological clinics just as he would attend surgical clinics if he were taking up surgery for the first time, for he who operates the modern high power installations is assuming as much responsibility as though he were performing major operations. The high road to radiology is a part of the medical highway, and while there are many rough detours and hard climbs there are no short cuts.

1520 Chapala.

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DISCUSSION

JOHN M. REHFISCH, M. D. (450 Sutter Street, San Francisco).—Doctor Ullmann's article is very interesting. It is a comfort to find a roentgen-therapist bold enough to relegate the impressive measuring devices to the group of nonessential instruments. After ten years of working with dosimeters, ionometers and iontoquantimeters of many kinds, I am ready to fall in behind Doctor Ullmann. Indeed, I am not sure that I might not go further than he does and express a doubt as to whether the *general* use of these instruments is not more often a danger than a safeguard. They are so delicate and suffer from such mysterious and vexatious ailments at crucial moments that they are likely to be quite a menace in the hands of any man who has the common human failing of making a god out of a machine. So many people seem to throw all common sense and reason to the winds in the face of a reading from a so-called "instrument of precision." And yet one is forced to admit that it would be a sore deprivation in one's own laboratory to be without some kind of a measuring instrument—even if one is suspicious of every measurement it makes.

Doctor Ullmann's observation that roentgen ray output varies with different tubes, if no filter is used, is of course quite true. It is also, however, worth mentioning that roentgen ray output is for practical purposes independent of tubes when heavy filters are used, provided the focal spot is within normal limits of size. I am speaking, of course, of new tubes with unpitted targets.

Another of Doctor Ullmann's remarks which seems—to me at least—to be worth heavy underlining is that the skin will stand an overdose of filtered radiation, when a comparable dose would do irreparable damage with no filter in place. The enormous factor of safety that a filter gives us is perhaps not so widely known as it should be. I am beginning to doubt whether we should *ever* use the unfiltered ray except when we deliberately go out after caustic effects in small areas.

I should also like to stress the fact that roentgen therapy is a biophysical job, that anyone of average intelligence can learn the essential physics of it in a very short time, but that when all that knowledge is added to him he will feel more and more impressed and depressed with the magnitude of the biological factors with which he has to deal. The more patients that he treats the more embarrassed he will be by our

almost unqualified ignorance of most of the fundamental laws of biological response to radiation. It is to men like Ewing (if there are any like him) that we look for some kind of a comprehensive synthesis of radiobiological data.

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R. R. NEWELL, M. D. (Stanford University Hospital, San Francisco).—To teach physicians the safe route in roentgenotherapy in one lesson is probably an ambition impossible of attainment. Doctor Ullmann has, however, pointed to the major dangers and ways to avoid them.

Time and distance I can measure surely, but I distrust all the other instruments, even the sphere gap. However, if they all hang together, if everything is running today just as it did yesterday, then confidence is a good deal restored. One instrument can hardly go wrong without getting out of line with the others. But *anything abnormal* in the operation of the machine must be solved before continuing treatment.

I try also to keep a healthy distrust of myself. Errors of memory and mistakes in mental arithmetic are productive of more "incidents" in roentgenotherapy than are lying instruments.

I would urge that the physician use always the same setting and vary his dosage by changing only time and distance. Two, or at most three, qualities are quite sufficient. Personally I would be content with only two filters, say one millimeter aluminum and one-half millimeter copper plus one millimeter aluminum. One who treats one disease with one millimeter aluminum and other with two millimeters aluminum is, in my opinion, merely making it difficult for himself to learn by clinical experience.

I would not urge on anyone such a repair risk as an iontoquantimeter or the like. Nevertheless, I do use an ionization instrument myself, for the advantage of one more check, and also because doses recorded in ionization units do presumably mean the same thing in Paris or Vienna as in San Francisco.

Doctor Ullmann has written the difference between large areas treated and small ones—physically measured. I would urge that the clinical difference is even greater. The application of 800 r might raise blisters on a large area, yet three times that dose can be given safely to an area five millimeters in diameter.

There is one variable that we have not learned to measure—the patient. Idiosyncrasy does exist, but the doses indicated by Doctor Ullmann will not cause patients to sicken and die, nor to break down and ulcerate. Idiosyncrasy has led me to disaster only where heavy dosage has been repeated several times. These were late ulcerations.

Doctor Ullmann's figure, seven per cent per day recovery, may be right for skin epithelium. It is the figure I use in my own calculations. But much more lasting changes occur in subcutaneous tissue after heavy roentgen radiation. The art suffers sadly from lack of knowledge of the fundamental biologic action of roentgen ray, and the differences in response of different tissues.

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A. U. DESJARDINS, M. D. (The Mayo Clinic, Rochester, Minnesota).—The requirements specified by Doctor Ullmann are entirely sound and one can hardly take exception to them. For the benefit of general practitioners who may read these requirements I should like to emphasize a few points. I should like to take exception first to the tendency of physicians as well as radiologists to use certain words which are misleading and which have little or no meaning. I refer for instance to the expression "deep" or "intensive" roentgen-ray treatment. These expressions have very little meaning unless they are accompanied by the electrical and other technical specifications which would make them intelligible. Consequently it would be more rational for the physician or surgeon referring a patient to the radiologist simply to say "roentgen treatment" and leave it to the radiologist to determine what is best under the circumstances; because, if the radiologist is worthy

of his hire, he is in conscience bound as a physician to do this. It is inconceivable that physicians who know little or nothing about radiotherapy should venture to dictate the details of such treatment.

Another point relates to roentgen ray apparatus and roentgen ray output. The importance of keeping roentgen ray apparatus and all the electrical connections thoroughly clean is not realized as it should be. To make this importance clear I need only relate the experience of the United States Navy as told by Surgeon-General Stitt himself. For some time the surgeon-general had been receiving from medical officers stationed in different parts of the tropics reports that, owing to the high humidity and temperature, the roentgen ray output was much lower than would be expected under better conditions. The number of such complaints led Surgeon-General Stitt to refer this problem to the physical laboratory maintained by the navy at Brooklyn. The first step in investigating the problem was to build a chamber in which both the humidity and temperature could be absolutely controlled. Then a series of tests with different makes of roentgen ray apparatus were made at different temperatures and with different degrees of humidity; it was found that if the apparatus were kept absolutely clean the maximum variation in output was about five per cent and that any variation above this was due to dirt.

At almost every meeting of radiologists and in almost every journal devoted to this subject, we find communications on or hear discussions of the subject of dosage. In most cases the communications or discussions revolve around the measurement of the quantity of roentgen rays by various ionization methods. I should like to emphasize that the measurement of the quantity of roentgen rays does not constitute the measurement of dosage in any respect. A dose of roentgen rays involves several factors: (1) the quantity of roentgen rays; (2) the quality of roentgen rays; and (3) an unknown x constituted by the patient. Therefore, to speak of a dose of x-rays as 1400 r does not mean very much unless it is accompanied by a specification of the quality of the rays by the precise method by which the treatment was applied to the patient, and also the condition of the patient, and I am coming to think more and more that the knowledge of the patient and his condition is the most important of all the factors.

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DOCTOR ULLMANN (Closing).—I am glad that Doctor Rehfsch has given me an opportunity to enlarge on the possibility of error when using measuring instruments. The more accurate the instrument the greater the care required to obtain reasonably accurate results. As an example, I offer the following procedure which I followed in making the tables given in this and other papers. To determine the average output of my tube, which is the essential thing, not the output at any particular moment, I would operate under my standard conditions and take from five to ten consecutive readings. All these readings must be within five per cent of their average or the setup rechecked for error. The average of these readings was recorded as the output at that particular time. This was repeated the same day or a few days later again recorded, and both records averaged for the average output of the machine. This procedure was repeated at intervals of weeks to months until I was fairly sure that my equipment was delivering radiation constant enough for all practical purposes. This must be done every few months, as I have found the output to change appreciably, requiring careful inspection of equipment and readjustment of rectifier gaps, switch, connections, etc. The tables, therefore, are the results of many observations extending over more than two years. A single set of observations may be very misleading.

Doctor Rehfsch spoke of the independence of the output of different tubes when filters were used. It should be noted that the variation in output was only spoken of in connection with unfiltered radiation.

It is true that there is a greater factor of safety with filtered than with unfiltered radiation, but it must be remembered that when damage is done it will extend deeper beneath the skin with filtered than with unfiltered rays because of their increased penetration.

I cannot agree with Doctor Newell on the statement that the difference between the large and small areas is much greater clinically than when physically measured, so far as these tables and the size of the doses under consideration are concerned. One would rarely use an area greater than 24 by 24 centimeters (576 square centimeters) and 800 r *when measured to include backscattering* will produce a light erythema on such an area in less than 50 per cent of individuals and a tan in about 75 per cent. It is equivalent to the minimum erythema or unit dose of radium given in the published tables of the Standardization and Research Committee of the American Radium Society. I cannot conceive of such a dose resulting in blisters except under exceptionally abnormal conditions. It must be borne in mind, however, that I refer to 800 r measured on the skin so as to include backscattering, not simply the tube output measured in air. It has long been known that many times the erythema dose may be applied to very small area without permanent damage, but such dosage must be reserved for the experienced radiologist and is beyond the scope of this paper.

I have used seven per cent as the daily recovery because it is below the eight per cent recovery for skin determined by Stenstrom and well within safe limits, as shown by the clinical results of several experienced radiologists. This factor and the reasons for its use were discussed by me in "The Relation of Fractional to Depth Dose."

It is fortunate that Doctor Desjardins stressed the importance of the clinical side of radiation therapy. It is too true that the profession as a whole considers roentgen therapy purely a technical problem and not infrequently turn their patients over to a lay technician for treatment. Roentgen therapy is primarily a clinical problem, and this paper was intended to assist the clinician and the clinician only in his difficulties with the physical aspects of formulating a dose of the roentgen rays.

In closing I wish to repeat what I said at the beginning of the paper. The recommendations and data are only the minimum requirements and are reasonably safe. To be even moderately qualified as a radiation-therapist the physician must consider them as only a few bricks with which to begin building the foundation of his knowledge.

DIFFICULT FRACTURES*

REPORT OF CASES

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DISCUSSION by Charles A. Dukes, M. D., Oakland; Ernest W. Cleary, M. D., San Francisco; N. Austin Cary, M. D., Oakland.

THIS paper is written, not with the thought of offering or suggesting anything new in the treatment of the commoner types of fractures. The common fractures are selected because in them lie the greatest number of problems and unsatisfactory results. In my opinion, there is no department of medicine and surgery more important than that of the treatment of fractures; the future happiness of vast numbers of injured depends on their proper treatment. Certainly

major abdominal surgery, both in technique and after-care, does not overshadow the reduction of dislocations and the care of injuries to such bones as the femur and humerus. While the mortality is not so great, especially in those individuals past the age of fifty years, the expense to the injured, the loss of time from work and home, the pain endured, is greater in fractures than in the average abdominal operation. One writer (Speed) has mentioned the great ado (not unnecessarily) made over a case of acute appendicitis for which every facility of a modern hospital is thrown into action (many nurses, laboratory staff, the surgical department and special nurses for the patient) and for which the average hospital stay is but ten to twelve days. Is the equivalent amount of attention required for fracture patients who are so prone to a multitude of complications? In such important injuries as fractures the hospital selected should have ample equipment, such as proper fracture tables, portable x-rays, orthopedic room, beds with framework fitted, a selection of splints, and the technique of the operating room and staff should be above question if open operation be necessary. The surgeon in charge should make sufficiently frequent personal inspection of his patient after reduction has been started. Too often the adjustment of the apparatus is left to a student nurse or to an orderly who knows little of the pathology of the fracture or the physiology of the limb. Extension apparatus easily gets out of adjustment and the bone fragments out of alignment, so that frequent inspection by the expert is essential to the happiness and comfort of the patient and, most important, to the best functioning of the injured limb.

No set rules of treatment can be followed in any type of fracture, the proper procedure having to be worked out separately in each instance. My experience has been that the open method is the procedure of choice in fractures of the long bones when satisfactory reduction has not taken place after six to ten days of faithful application of some form of extension. In a well-appointed hospital, with a skilled surgeon, the operative method of reducing fractures is today performed with vastly increased safety. In this manner, as a rule perfect apposition of fragments is obtained and the limb restored to absolutely normal function when otherwise much unhappiness would have occurred from deformity and loss of function.

Time will not permit of any detailed discussion of types of apparatus for conservative treatment or the various methods of fixation in open operation.

The cases reported in this paper are those which were complicated with other fractures or which presented some difficult problem.

REPORT OF CASES

CASE 1.—Lester P., age eight, fell from a tree. The distal ends of the left radius and ulna were forced through the volar surface of the wrist and projected into the dirt and grass. He was cared for at a county hospital for the following five days. X-rays taken there showed that the distal end of the radius had separated from the epiphysis, leaving this distal fragment in its normal articulation with the wrist.

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